Executive Summary

A Model for Assessment of Ecological Interactions Among Living Marine Resources in the Gulf of Mexico: Implications for Bycatch Management and Shrimp Production

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Introduction

Background

In recent years, the Gulf of Mexico shrimp fishery (*Penaeus* spp.) has experienced increased scrutiny regarding the impacts of trawl bycatch on natural resources. Bycatch is comprised of non-targeted species which are captured incidentally during trawling operations and are released dead, injured or stressed. Conservation agencies and environmental organizations generally view trawling as a destructive or wasteful fishery that negatively impacts other living marine resources (Fowle and Bierce 1992). Globally, shrimp trawling has been identified as the fishery with the largest and most serious bycatch issues (Alverson et al. 1994). Excess bycatch in shrimp trawls is seen as an important cause for declines in stocks of some commercially important finfish, endangered sea turtles and other living resources in the Gulf of Mexico (Henwood and Stuntz 1987; Goodyear and Phares 1990; National Research Council 1990; Caillouet et al. 1991; Goodyear 1991). Measure to reduce bycatch (bycatch reduction devices) have been proposed to alleviate such declines. These measures may have the effect of releasing more shrimp predators or allowing small fish to grow larger and thus become predators. Shrimp stocks might then be impacted by increasing the incidence of finfish predation. Although the interaction of shrimp and finfish predators in a Gulf of Mexico estuary has been described in detail (Minello et al. 1989), limited information is available regarding shrimp predation in offshore waters, and its effect on shrimp stocks. Development of an ecosystem-based model is desirable to guide research and management. However, it is important to remember that predictive results of such models are based on assumptions and the quality information available.

Previous Modeling Efforts

Research completed in the early 1980's resulted in the development of several models to examine potential fish predation on shrimp stocks in offshore waters (Browder 1983; Sheridan et al. 1984a). The purpose of the models was that reduction of shrimp trawl bycatch affected shrimp stock dynamics and, ultimately, shrimp fishery yield. The models were used to simulate dynamics of living resources in the ecosystem subsequent to bycatch reduction (perturbation). Initially, quantitative data which specified *Penaeus* as a prey item was minimal and indicated a low incidence of finfish predation on shrimp (Browder 1983; Sheridan et al. 1984a). Information regarding competition among fish species was even more limited. One model utilized traditional population dynamics techniques (matrix operations); the other was an ecosystem simulation model with numerous compartments representing different trophic groups linked by energy flow and nitrogen cycling within the system.

The population dynamics model indicated that even the most favorable discard practices could increase shrimp harvest by only 8% (Sheridan et al. 1984a). This assumes no discards of shrimp and a high rate of discards for bottomfish. Furthermore, a major assumption was that reassimilation of fish discards would "be directly translated into shrimp yield" (Sheridan et al. 1984a). However, the authors indicated that the actual benefit would probably be less since assimilation rates in the model were overestimated; therefore, results from the population dynamics model were not considered to be very accurate. The trophic model provided greater flexibility for inclusion of biotic and abiotic factors such as riverine input of nitrogen, solar radiation, plankton and benthic components, fishing effort, and stocks of shrimp, bottomfish, migratory and pelagic finfish, large predators (dolphins), scavengers (sharks), and utilization of bycatch by fishermen. Results from this model suggested that shrimp production (biomass) would decline approximately 25% if discards were reduced by 50% through utilization (i.e., removal of biomass from the ecosystem). Model results also indicated that only an 8% reduction in shrimp production would be observed with the introduction of trawls which reduced bycatch, assuming that excluded finfish do not exhibit selective predation against shrimp as a prey item. Consequently, the authors concluded that using bycatch reduction devices (BRD's) or similar techniques to reduce finfish capture would result in no long term effect on shrimp harvest if finfish exhibited even moderate selectivity against shrimp as prey. Shrimp biomass would decrease initially, but shrimp stocks would rebound and stabilize after the first or second year following implementation of BRD's (Browder 1983; Sheridan et al. 1984). The trophic model of Browder has been generally accepted in evaluating predator-prey interactions in the shrimp fishery since data from many different research efforts up to that time were used to parameterize and quantify the model.

New Research

Since 1980, when the Browder models were developed, new research has provided additional information on predator-prey interactions between shrimp and finfish stocks in the Gulf of Mexico. Scientists of the Southeast Fisheries Science Center (SEFSC) and other investigators have continued to examine foods of trawl-susceptible and coastal pelagic fishes and consequently identified the dominant shrimp predators and their frequency of predation on penaeid shrimp (Naughton 1981; Divita et al. 1983; Manooch and Haimovici 1983; Manooch and Hogarth 1983; Manooch et al 1983; Saloman and Naughton 1983a, 1983b; Sheridan and Trimm 1983; Sheridan et al. 1984b; Sheridan, unpublished data). Of

161 fish species examined, only 14 fish species have been identified as predators on shrimp of the genus *Penaeus*. These include Atlantic croaker (*Micropogonias undulatus*), sand seatrout (*Cynoscion arenarius*), spotted seatrout (*Cynoscion nebulosus*), silver seatrout (*Cynoscion nothus*), ocellated flounder (*Ancylopsetta quadrocellata*), inshore lizardfish (*Synodus foetens*), bighead searobin (*Prionotus tribulus*), smooth puffer (*Lagocephalus laevigatus*), red snapper (*Lutjanus campechanus*), lane snapper (*Lutjanus synagris*), Spanish mackerel (*Scomberomorus maculatus*), rock sea bass (*Centropristis philadelphica*), dwarf sand perch (*Diplectrum bivittatum*), and Atlantic sharpnose shark (*Rhizoprionodon terraenovae*). The relative importance of shrimp predation by each of these species is presented in Table 1. Sand seatrout represent the dominant predator of shrimp in gulf waters, despite the low occurrence of *Penaeus* in their stomachs. This is attributed to the abundance of the sand seatrout population in the Gulf of Mexico (NMFS, unpublished data).

Since 1990, research on bycatch characterization and bycatch reduction devices (BRD's) have produced data on the magnitude, composition, and distribution of bycatch species captured in trawls and on effectiveness of trawls equipped with BRD's. Bycatch characterization studies (> 450 trips, > 4,000 observer days) have recorded > 250 species of finfish. Characterization data includes size and weight characteristics of fish as well as catch per unit effort (CPUE) by area, season, and depth fished (NMFS, unpublished data). BRD evaluations indicate that certain gear types can release up to 79% of a given species (biomass; NMFS, unpublished data). Seven species of known shrimp predators were evaluated with respect to exclusion from trawls using BRD's. CPUE was reduced for Atlantic croaker, Spanish mackerel, lane snapper, and red snapper. CPUE remained unchanged for rock sea bass, smooth puffer and inshore lizardfish.

A review panel of scientists from NMFS and academic institutions was assembled to examine areas for improvement of the existing models. This working group identified the need for inclusion of additional functional relationships in the model. In addition, new parameters were identified for components describing stocks of phytoplankton, zooplankton, bycatch, discards, shrimp and several finfish groups (reefish, pelagics, etc.).

Methods

Model Design

The design of the new model follows Browder (1983) and Sheridan et al. (1984a). A generalized version of the model is shown in Figure 1. Nitrogen is used as the common currency of material flow within the model since it can quantitatively describe biotic (stocks) and abiotic (environmental) components of the model. Therefore, nitrogen substitutes for biomass of living marine resources through simple conversion of biomass (kg) to nitrogen units (mg N_2/m^2). The model is programmed using the Stella/iThink simulation software for Macintosh computer platforms. The model contains 110 variables including:

1. ***Abiotic components***: river runoff, sedimentation rates, water temperature, and photoperiod.

2. ***Biological components***: N_2 pools (inorganic and organic), planktons, benthos (infauna and epifauna), crustaceans, finfish (bottomfish, pelagics, migratory fish), dolphins, sharks and birds.

3. ***Ecological components***: predation, excretion, respiration, natural mortality, assimilation, and denitrification rates.

4. ***Fishery components***: species-directed effort, catch, discards, and bycatch reduction rates.

The bottomfish component of the model includes reef fish species such as red snapper which are susceptible to incidental capture in trawls at some stage of their lives.

Data Input and Model Parameterization

Examples of the inputs and outflows of nitrogen for individual stocks of living marine resources are shown in Figure 2. The nitrogen inputs for each component in the model are detailed in Table 2. Removal of material in nitrogen components is achieved through burial (sedimentation), denitrification, or uptake by resources. In stocks of living marine resources, removal of nitrogen from the stock is achieved through respiration, decomposition, harvest, and predation by other resources. The majority of the data used to parameterize the model was taken from published reports on life history and ecological requirements of individual species. Data on river flow into the Gulf of Mexico (Atchafalaya and Mississippi Rivers) were obtained from the U.S. Army Corps of Engineers, New Orleans District. Data from NMFS statistical surveys were used to quantify fishing effort and landings for commercial species of shrimp and fish. Due to the lack of quantitative information, the components describing dolphins, sharks, and sea birds were not utilized in the simulations despite anecdotal reports that these stocks could have significant impacts on other resources, especially through predation of discards. Because these components were closed off (i.e., no predation on other components), the simulations results presented in this report must be viewed as preliminary, but probably represent the upper bounds of the effects on the shrimp stocks.

Results

Model Simulations

Output of the model is contingent upon the assumptions and data constraints imposed on the parameters and simulations. The model was parameterized using data for the Gulf of Mexico offshore waters, from Alabama to Brownsville (NMFS statistical areas 11-21). Mortality of discards from bycatch was assumed to be 100% for simulation purposes. This implies 'worst-case' scenarios with regard to the fate of the discards. Bycatch that is not scavenged or consumed by predators returns to the general stock of organic nitrogen in the ecosystem. The model was used to simulate the ecosystem for a one year period under four hypothetical perturbations. Results of these scenarios were compared against baseline simulations to examine the effect of bycatch management measures (i.e., BRD's) on shrimp stocks. The baseline conditions considered are before BRD-implementation into the fishery. It is important to note that the results reflect differences in production within the stock of shrimp, and not fishery yield. Results as they may affect shrimp stocks are reported below and summarized in Figures 3-6. No similar analyses was completed for other resources or stocks in the model.

Model Simulations - BRD effects

Scenario 1: BRD effect - equivalent release of finfish.

The first simulation is a general overview of the effects of bycatch reduction policy on shrimp stocks. It was run for comparative purposes with the other simulations and is to demonstrate the BRD effect if all finfish were released at an equivalent rate. This scenario examines reduction in biomass of all bottomfish by 10, 25 & 50%, without selective BRD effects. Values for stocks of shrimp (biomass represented by nitrogen) with each simulation were compared to the baseline values. Results indicate a general decrease in shrimp stocks by reduction of finfish biomass. Over a one year period, shrimp stocks declined by 0.8% with 10% bycatch reduction, by 5.5% with bycatch reduction of 25%, and by 10.7% with 50% decrease in bycatch (Figure 3). The decline in shrimp stocks is attributed to an increase in the abundance of bottomfish predators and a reduction in the organic nitrogen pool (which is augmented by discards in the baseline simulation). However, predation on shrimp is the primary reason for the differences because bottomfish nitrogen stock increased 4-19% due to bycatch reduction.

Scenario 2: BRD effects - selective release of finfish.

In actuality, BRD's do not release all finfish at equivalent rates. Some finfishes are released at higher rates than others, and others are not released at all. However, because restoration of red snapper stocks is driving the bycatch reduction policy, BRD's have been tested with the goal of achieving a 50% reduction in mortality of juvenile red snapper. Three gear types tested by NMFS and evaluated through the bycatch research program approach or attain this goal. These BRD's include a front position fisheye (30 mesh location) on top of the trawl, a middle position fisheye (45 mesh location), and the extended funnel design. However, each of these gear types exhibits variable exclusion rates with respect to different finfish species. Analysis of this information reveals that exclusion of these species accounts for a reduction in CPUE (by weight) of 30.6% (front fisheye), 29.6% (middle fisheye), and 34% (extended funnel) of nitrogen in the bottomfish component of the model. This amount is returned to the sea alive and augments the stock of fish which may prey on shrimp. Incorporating these data into the model yields a reduction in shrimp stocks of 6.7% for the front position fisheye, 5.9% for the middle position fisheye, and 8.2% for the extended funnel design (Figure 4). The release of finfishes by BRD's will allow more larger sized fish in the population. An important assumption is that finfish predation on shrimp is expected to change as fish increase in size (i.e., depending on food habits of larger fish predation on shrimp may either increase or decrease).

Model Simulations - Finfish size effects

Scenario 3: Finfish size effect - increase in shrimp predation.

Finfish excluded from trawls will continue to grow, possibly leading to increased consumption rates on shrimp prey. Ecologically, consumption of prey types by finfish is largely dependent on the size structure of both predator and prey populations. Smaller fish which could not prey on the larger shrimp in the Gulf of Mexico may be able to do so if given the opportunity to grow larger. Data to describe changes in predation or growth rates of finfish are not currently adequate for use in the model developed here. Consequently, a sensitivity analysis of variable predation rates was undertaken to provide some insight as to the impacts on shrimp stocks. An average bottomfish exclusion rate (31.4%; CPUE by weight) for the three gear types described in Scenario 2 was used for this sensitivity analysis. This yields a decrease in shrimp stocks by 6.2% over baseline conditions. Predation rates were then increased by 10, 25, and 50%, and results from one year simulations were compared with the baseline values. A 10% increase in the predation rate on shrimp by excluded bycatch results in an 8.2% decline in shrimp stocks. Shrimp stocks declined by 10.8% with a 25% increase in predation rates, and by 16.7% with a 50% increase in predation rates by excluded finfish (Figure 5). The relationship between finfish predation rates and shrimp stocks appears to be linear and is discussed below.

Scenario 4: Finfish size effect - decrease in shrimp predation.

As fish grow they may change dietary habits. Under this assumption, fish of larger size will decrease predation on shrimp due to preference for alternate prey. Optimal foraging theory and research on predator-prey interactions of fish provide evidence of such occurrences in estuarine and oceanic ecosystems. Using our model, a series of simulations (similar to scenario 3 above) were conducted to examine the effect of decreasing predation rates by excluded fish on shrimp stocks. As in the previous simulation scenario, the baseline conditions reflect general bottomfish exclusion rates of 31.4% (CPUE by weight). In this set of sensitivity analyses, predation rates were decreased by levels of 10, 25, and 50%. Generally, a reduction in the predation rates by excluded fish has smaller impacts on the shrimp stocks. A 10% decrease in predation on shrimp by excluded bycatch results in a 4.1% decline in shrimp stocks, and a 25% decrease in predation rates reduced shrimp stocks by 1.3%. As predation rates continue to decrease, there could be some benefit to the shrimp stocks: a 50% decrease in predation rates by excluded finfish resulted in a 4.7% increase in the amount of nitrogen in the shrimp stock (Figure 6). The interaction between finfish predation rates and shrimp production is represented by a linear relationship (Figure 7). For every percent change in predation rate, there is 0.21% change in shrimp stock size.

Conclusions and Recommendations

Revision of the ecosystem-based bycatch model is enhanced through incorporation of new information on bycatch characterization, stock assessments, and efficiencies of bycatch reduction devices. The large number of variables in the model represent movement toward a realistic evaluation of ecosystem effects in the dynamics of the Gulf of Mexico shrimp fishery. The initial output, however, is of relatively low resolution due to aggregation of information within larger components (e.g., seatrouts, snappers, etc. are described within the bottomfish group). Data used to parameterize the model include specific rates for individual components (e.g., sediment burial rates, respiration rates of shrimp) and general trends or average values for other components (e.g., species-directed effort patterns, respiration rates for benthic infauna, natural mortality rates for phytoplankton and zooplankton). The model is used to simulate several different hypothetical scenarios which encompass possible changes in ecosystem dynamics with the implementation of bycatch management policy. Depending on bycatch exclusion rates and assumptions relative to predator selection of shrimp prey, simulated shrimp stock biomass could increase by 4.7% or decrease by 17%. The decrease in the shrimp stocks is primarily due to predation, but is also due to a reduction in the amount of nitrogen recycled from discards. However, nitrogen returned to the ecosystem through discards is minimal in comparison to the rather large input from riverine sources.

These model simulations indicate possible outcomes within the fishery and the ecosystem. A number of factors, some remaining unmeasured, may have profound effects on the actual response of the ecosystem to changes in resources. The fate of discards from the Gulf of Mexico trawl fishery is not fully understood. Generally, scientific data are lacking to adequately address the scope of the ecosystem, its inhabitants, and their interactions. This is especially evident with respect to stock size, predator-prey interactions, and competition among individual groups such as bottomfish, sharks, birds, and dolphins. Our assumption of 100% mortality of discards has not been investigated or documented. Other assumptions with inadequate information include: changes in fishing effort due to variability in size or mobility of the shrimp fleet, variability in recruitment or survivability for living resources, changes in life history within stocks, loss of habitat, selection of alternate prey, and competition among species. Over the past 5 years, the natural variability of production in the shrimp fishery has approached 12% of average landings. When considering the potential decrease in shrimp stocks due to bycatch reduction and higher predation, it is likely that changes or impacts in production will be within the natural annual variability and therefore may be difficult to detect. The actual effects of bycatch management on the shrimp resources will remain undetermined until bycatch reduction is implemented and follow-up observations are completed.

References

Alverson, D. L., M. H. Freeberg, S. A. Murawaski and J. G. Pope, 1994. A global assessment of fisheries bycatch and discards. FAO Technical Series Paper, No. 339. Food and Agriculture Organization of the United Nations (FAO), Rome, Italy. 233 pp.

Browder, J., 1983. A simulation model of a near-shore marine ecosystem of the north central Gulf of Mexico. In: Turgeon, K. W. (ed.), Marine Ecosystem Modeling. NOAA/National Environmental Satellite, Data and Information Service, Washington, D.C. pp 179-222.

Caillouet, C. W., M.J. Duronslet, A.M. Landry, D. B. Revera, D. J. Shaver, K. M. Stanley, R. W. Heinly and E. K. Stabenau, 1991 Sea turtle strandings and shrimp fishing effort in the northwestern Gulf of Mexico, 1986-1989. Fishery Bull., 89: 712-718.

Divita, R., M. Creel and P. F. Sheridan, 1983. Foods of coastal fishes during brown shrimp, *Penaeus aztecus*, migration from Texas estuaries (June-July 1981). Fishery Bull., 81: 396-404.

Fowle, S., and R. Bierce, (editors), 1991. Proceedings of the shrimp trawl bycatch workshop, November 22-23, 1991. St. Petersburg, FL. Center for Marine Conservation, 183 pp.

Goodyear, C. P, 1991. Sensitivity of shrimp-bycatch mortality estimates to natural mortality for red snapper. National Marine Fisheries Service, Southeast Fisheries Science Center, Miami Laboratory, Miami, Fl., Contribution, MIA 90/91-28. 6 pp.

Goodyear, C. P. and P. Phares, 1990. Status of red snapper stocks of the Gulf of Mexico - Report for 1990. National Marine Fisheries Service, Southeast Fisheries Science Center, Miami Laboratory, Miami, Fl. Laboratory Report, Contribution # CRD-89/90-05.

Henwood, T. A. and W. E. Stuntz, 1987. Analysis of sea turtle captures and mortalities during commercial shrimp trawling. Fishery Bull., 85: 813-817.

Manooch, C. S. and M. Haimovici, 1983. Foods of greater amberjack, *Seriola dumerili*, and almaco jack, *Seriola rivolana* (Pisces:Carangidae), from the South Atlantic Bight. J. Elisha Mitchell Sci. Soc., 99: 1-9.

Manooch, C. S. and W. T. Hogarth, 1983. Stomach contents and giant trematodes from wahoo, *Acanthocybium solanderi*, collected along the south Atlantic and Gulf coasts of the United States. Bull. Mar. Sci., 33: 227-238.

Manooch, C. S., D. L. Mason and R. S. Nelson, 1983. Food and gastrointestinal parasites of dolphin, *Coryphaena hippurus*, collected along the southeastern and Gulf coasts of the United States. U.S. Dept. of Commerce, NOAA Tech. Memo., NMFS-SEFC-124, 36 pp.

Minello, T. J., R. J. Zimmerman and E. X. Martinez, 1989. Mortality of young brown shrimp *Penaeus aztecus* in estuarine nurseries. Trans. Am. Fish. Soc., 118: 693-708.

National Research Council, 1990. Decline of the sea turtles; causes and prevention. National Academy Press, Washington DC, 259 pp.

Naughton, S. P. and C. H. Salomon, 1981. Stomach contents of juveniles of king mackerel (*Scomberomorus cavalla*) and Spanish mackerel (*S. maculatus*). NE Gulf Sci., 5: 71-74.

Salomon, C. H. and S. P. Naughton, 1983a. Food of king mackerel, *Scomberomorus cavalla*, from the southeastern United States, including the Gulf of Mexico. U.S. Dept. of Commerce, NOAA Tech. Memo., NMFS-SEFC-126, 25 pp.

Salomon, C. H. and S. P. Naughton, 1983b. Food of Spanish mackerel, *Scomberomorus maculatus*, from the Gulf of Mexico and southeastern seaboard of the United States. U.S. Dept. of Commerce, NOAA Tech. Memo., NMFS-SEFC-128, 22 pp.

Sheridan, P. F. and D. L. Trimm, 1983. Summer foods of Texas coastal fishes relative to age and habitat. Fishery Bull., 81: 643-647.

Sheridan, P. F., J. A. Browder and J. E. Powers. 1984a. Ecological interactions between penaeid shrimp and bottomfish assemblages. In: Gulland, J. A. and B. J. Rothschild (eds.), Penaeid Shrimps - Their Biology and Management. Fishing News Books, Ltd., Farnham, Surrey, UK. pp. 235-254.

Sheridan, P. F., D L. Trimm and B. M. Baker. 1984b. Reproduction and food habits of seven species of northern Gulf of Mexico fishes. Contr. Mar. Sci., 27: 175-204.

Table 1. Fish predators of penaeid shrimp in the gulf of Mexico, ranked in order of importance (based on predation rates and magnitude of predator stock). The table provides information on percent frequency of occurrence of shrimp in stomachs examined and abundance of fish captured in trawls during NMFS bycatch characterization surveys on commercial vessels during 1992-1994 (offshore only).

	Scientific Name	Common Name	% Frequency of Penaeus in Stomachs	Mean Fish/Hr. In Trawls
1	*Cynoscion arenarius*	Sand Seatrout	0.55	16
2	*Cynoscion nebulosus*	Spotted Seatrout	4.76	< 1
3	*Micropogon undulatus*	Atlantic Croaker	0.02	177
4	*Synodus foetens*	Inshore Lizardfish	0.19	18
5	*Centropristis philadelphica*	Rock Sea Bass	0.12	18
6	*Ancylopsetta quadrocellata*	Ocellated Flounder	1.14	< 1
7	*Diplectrum bivittatum*	Dwarf Sand Perch	0.08	12
8	*Lutjanus synagris*	Lane Snapper	0.42	< 1
9	*Lagocephalus laevigatus*	Smooth Puffer	0.38	< 1
10	*Prionotus tribulus*	Bighead Searobin	0.32	1
11	*Rhizoprionodon terraenovae*	Atlantic Sharpnose Shark	2.17	2
12	*Scomberomorus maculatus*	Spanish Mackerel	0.19	< 1
13	*Lutjanus campechanus*	Red Snapper	0.09	2
14	*Cynoscion nothus*	Silver Seatrout	0.06	2

Table 2. Nitrogen inputs for individual components in the ecosystem model. Despite their inclusion as a functional relationship in the model, some of the specific parameters may be set to zero due to lack of quantitative data.

Model Component/Stock	Source of Nitrogen Input
Organic Animal Nitrogen	Riverine input, zooplankton fecal pellets, discarded bycatch (dead), natural mortality of benthos, shrimp, other crustaceans, fish, sharks, dolphins
Organic Plant Nitrogen	Phytoplankton mortality and unassimilated phytoplankton
Dissolved Inorganic Nitrogen	Riverine input, degradation of organic nitrogen (plant and animal), excretion from zooplankton, shrimp, crustaceans, fish, sharks and dolphins
Phytoplankton	Riverine input, inorganic and organic nitrogen pools
Zooplankton	Phytoplankton, organic nitrogen pools
Benthos	Organic Nitrogen Pools
Shrimp	Organic nitrogen (plant and animal), benthos
Other Crustaceans	Organic animal nitrogen, benthos
Pelagic Fish (Menhaden)	Phytoplankton, Zooplankton
Bottomfish and Reefish	Organic nitrogen (plant and animal), benthos, shrimp, crustaceans, discards
Migratory Fish	Shrimp, crustaceans, pelagics, bottomfish
Dolphins	Shrimp, crustaceans, pelagics, bottomfish, migratory fish, discards
Sharks	Shrimp, crustaceans, pelagics, bottomfish, migratory fish, dolphins, discards
Birds	Discards

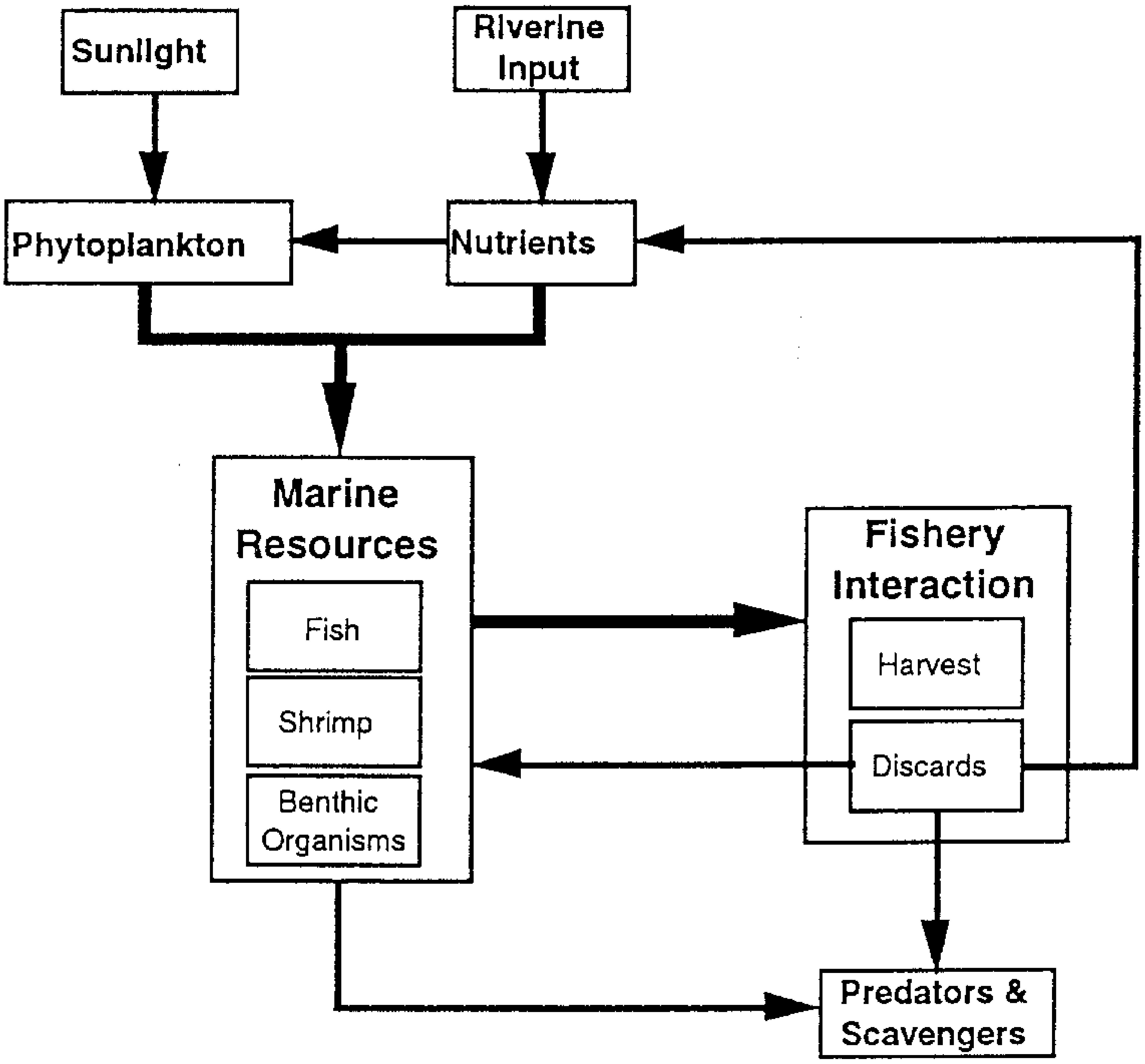

Figure 1. Generalized conceptual ecosystem model to evaluate impacts of shrimp trawl bycatch in the Gulf of Mexico.

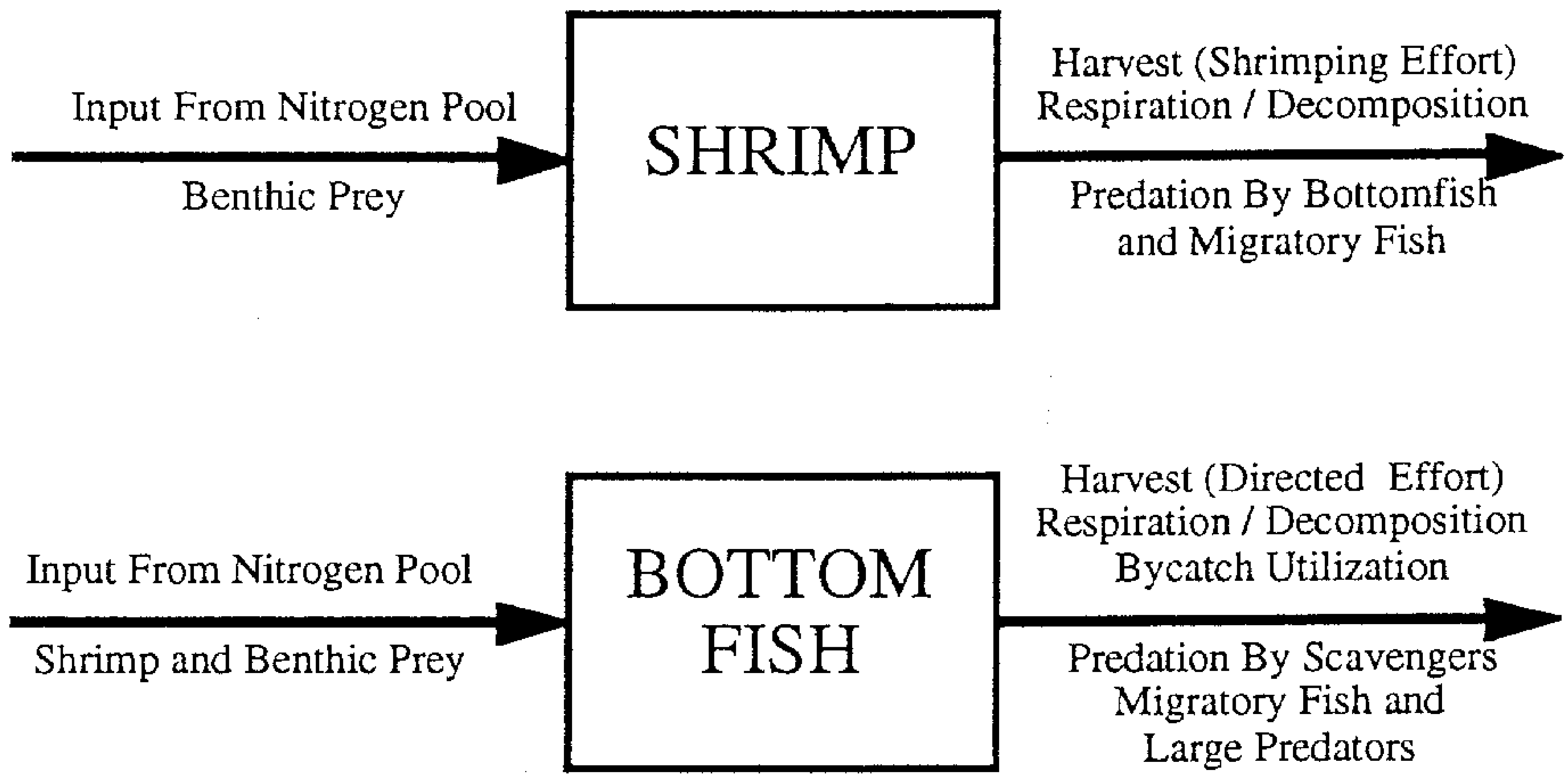

Figure 2. Input and removal of nitrogen from stocks of shrimp and bottomfish. The flows of nitrogen in components of all living marine resources follow the general pattern shown.

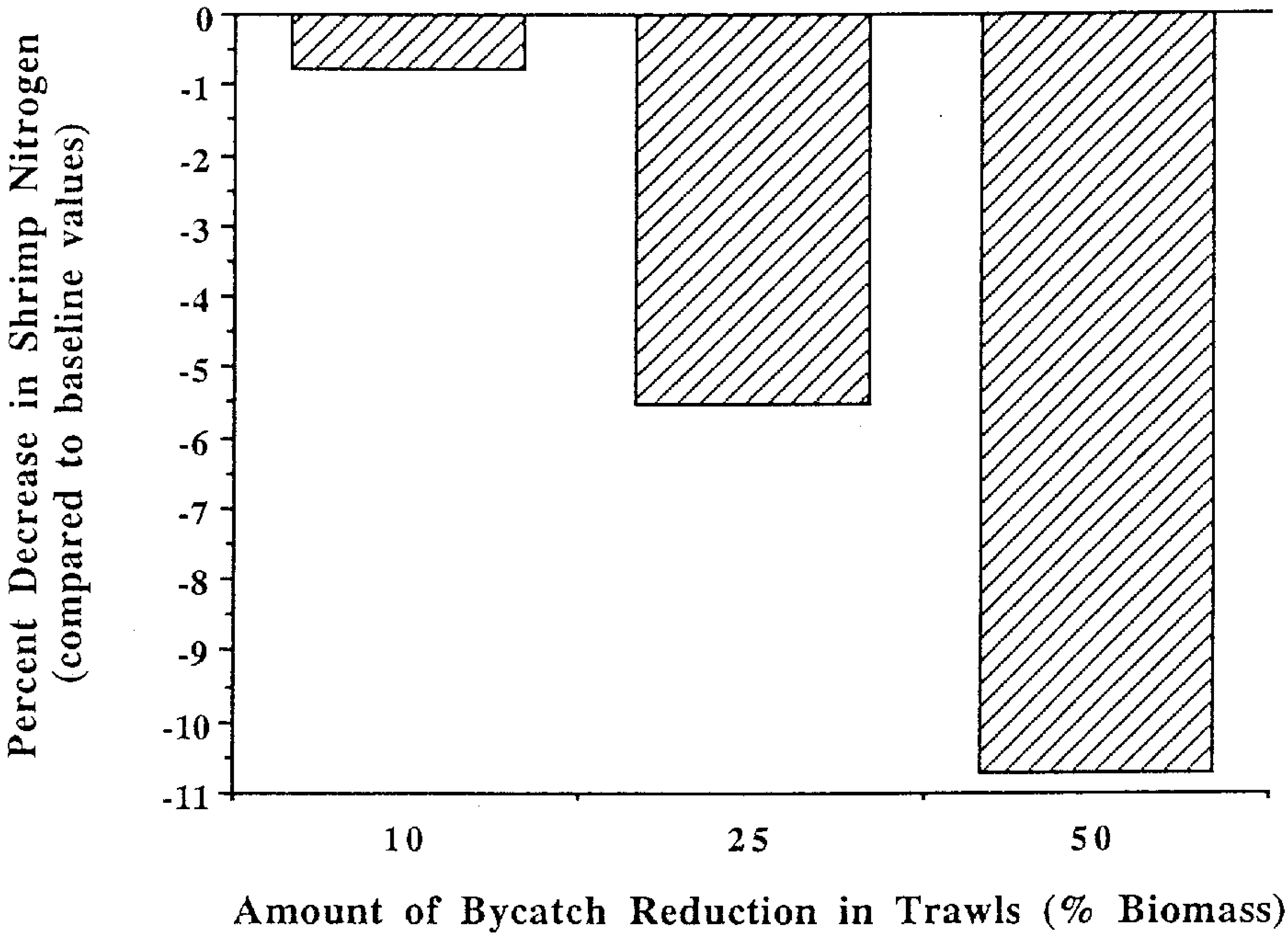

Figure 3. Decrease in size of shrimp stocks for simulation scenario 1 (predation increases due to greater numbers of fish in the ecosystem).

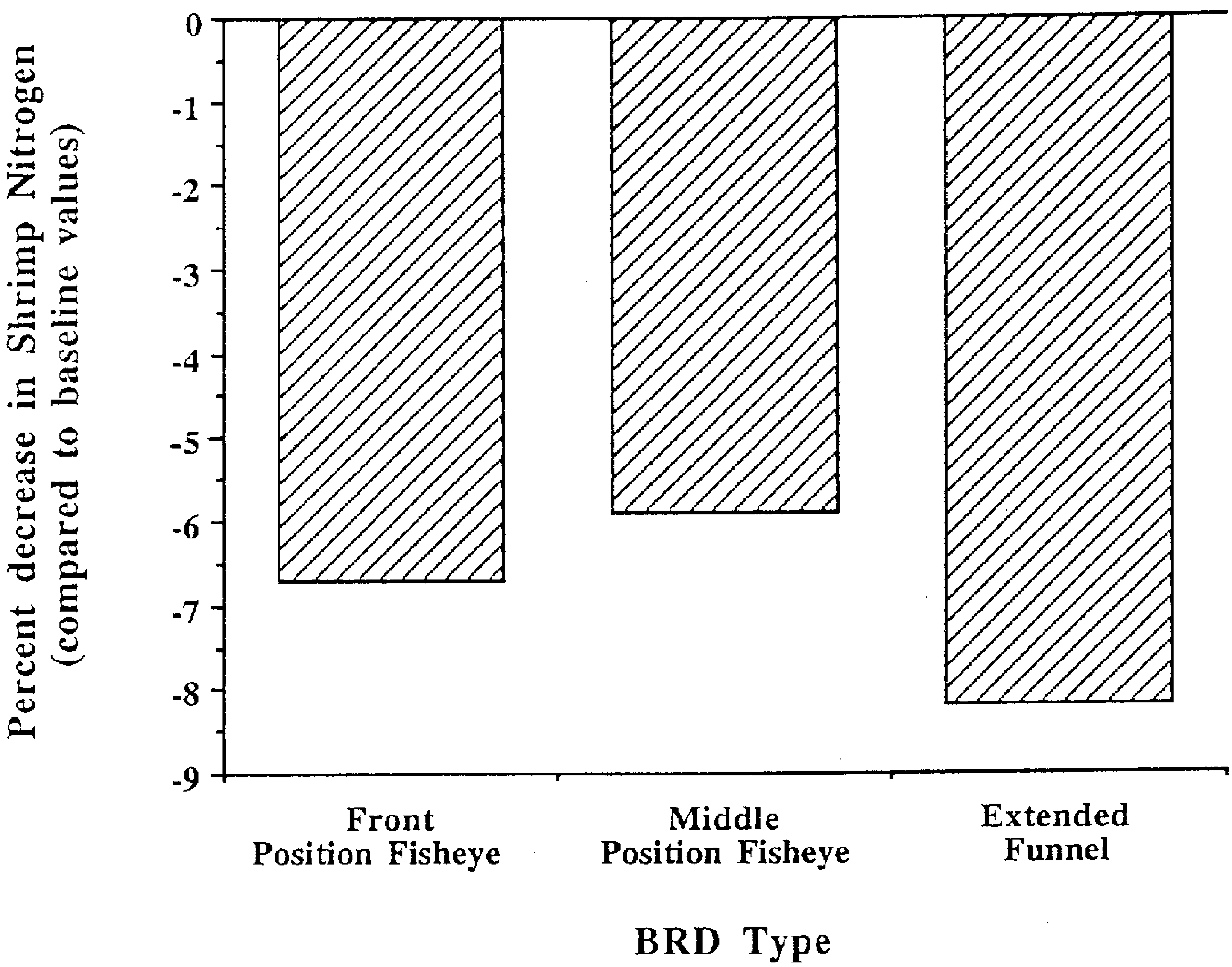

Figure 4. Decrease in size of shrimp stocks for simulation scenario 2 with 3 types of bycatch reduction devices (BRD's): predation increases only for excluded fish.

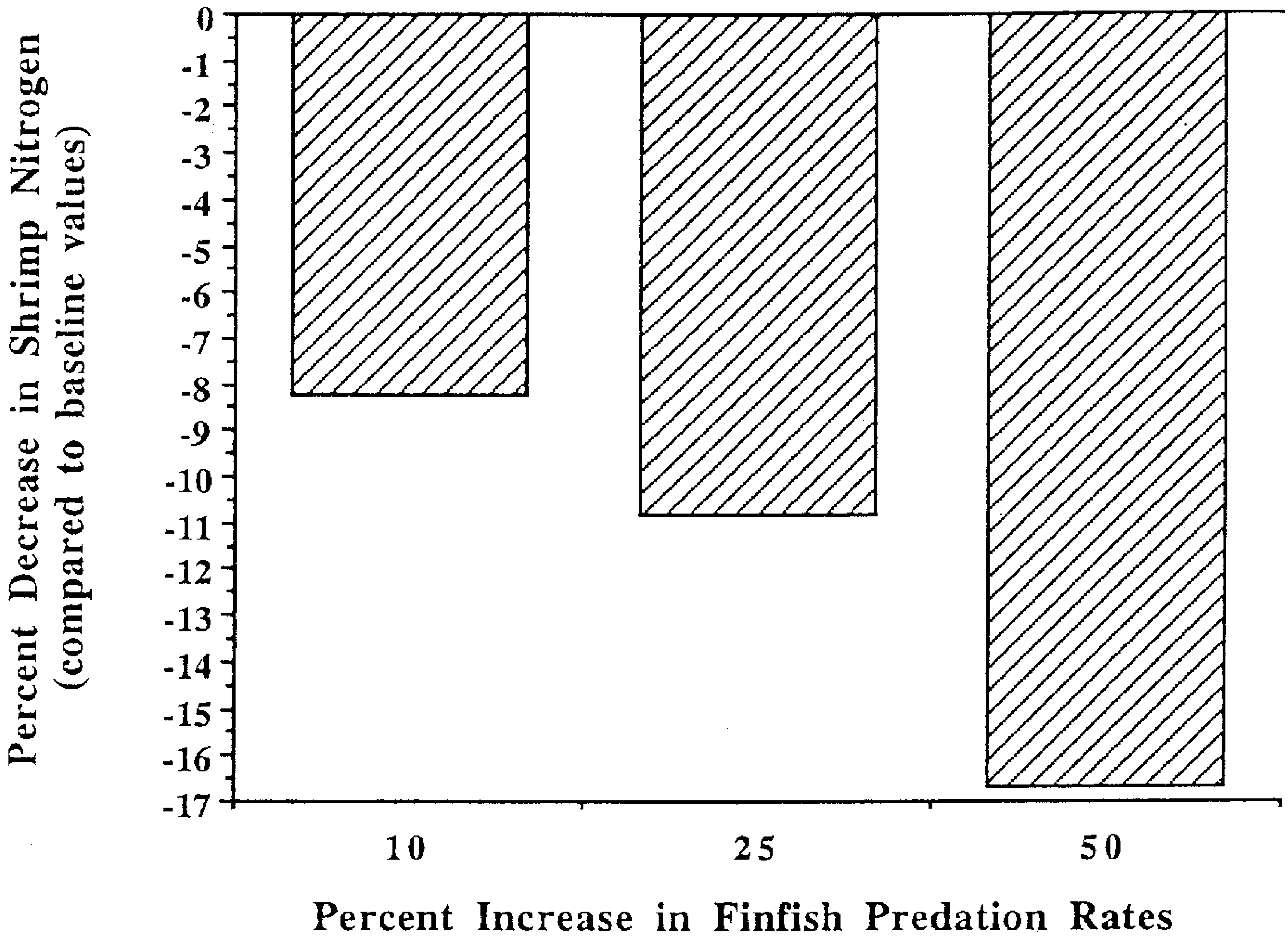

Figure 5. Decrease in size of shrimp stocks for simulation scenario 3 with average bycatch reduction: predation rates increase as the size structure of fish stocks change. As small fish are allowed to continue growing, they might attain a size at which they become predator on shrimp, thus increasing the overall predation rate.

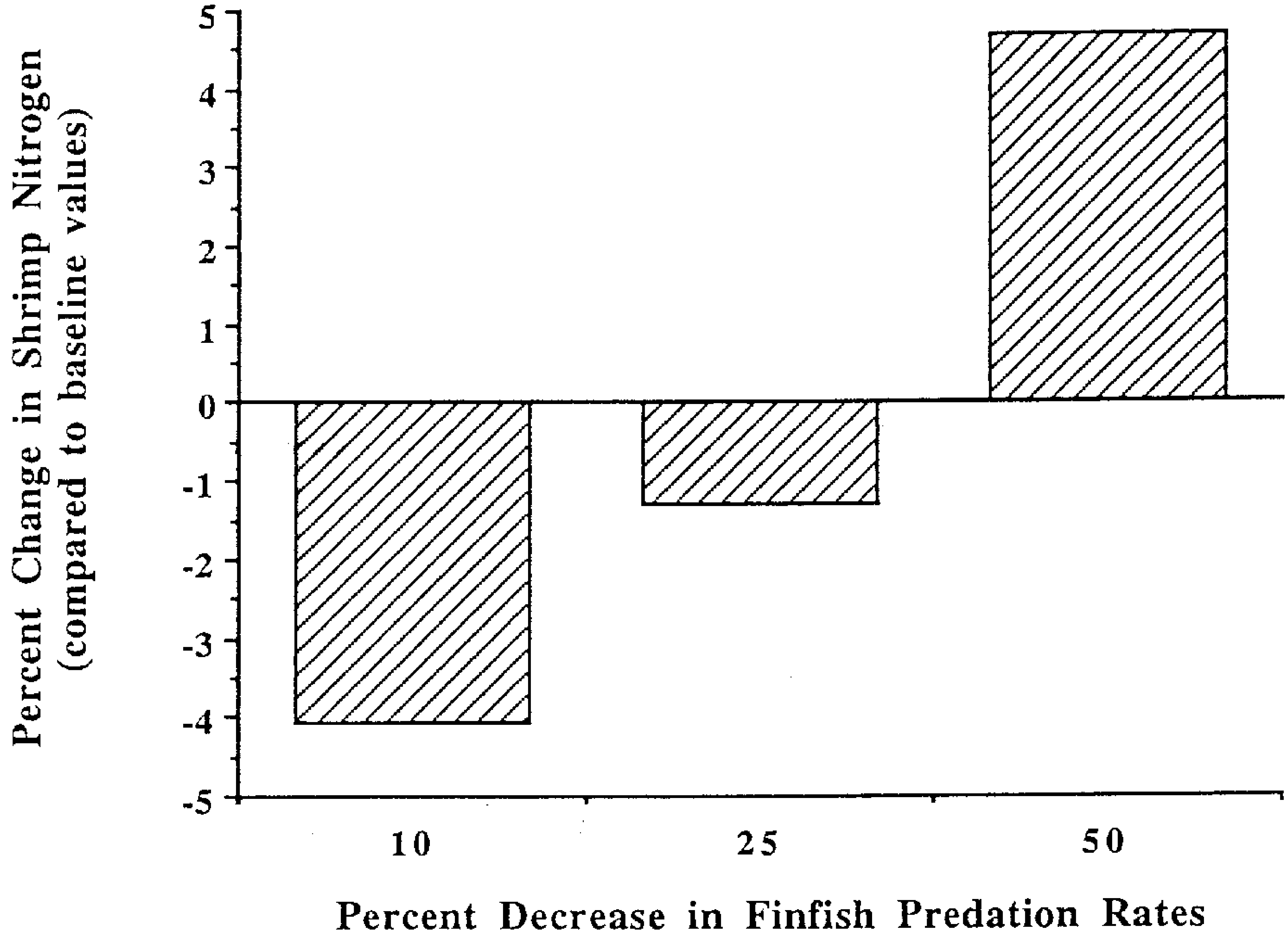

Figure 6. Decrease in size of shrimp stocks for simulation scenario 4 (with average bycatch reduction): predation rates decrease as the size structure of fish stocks change. This scenario assumes that as shrimp predators continue to grow, they will select for alternate prey items over shrimp.

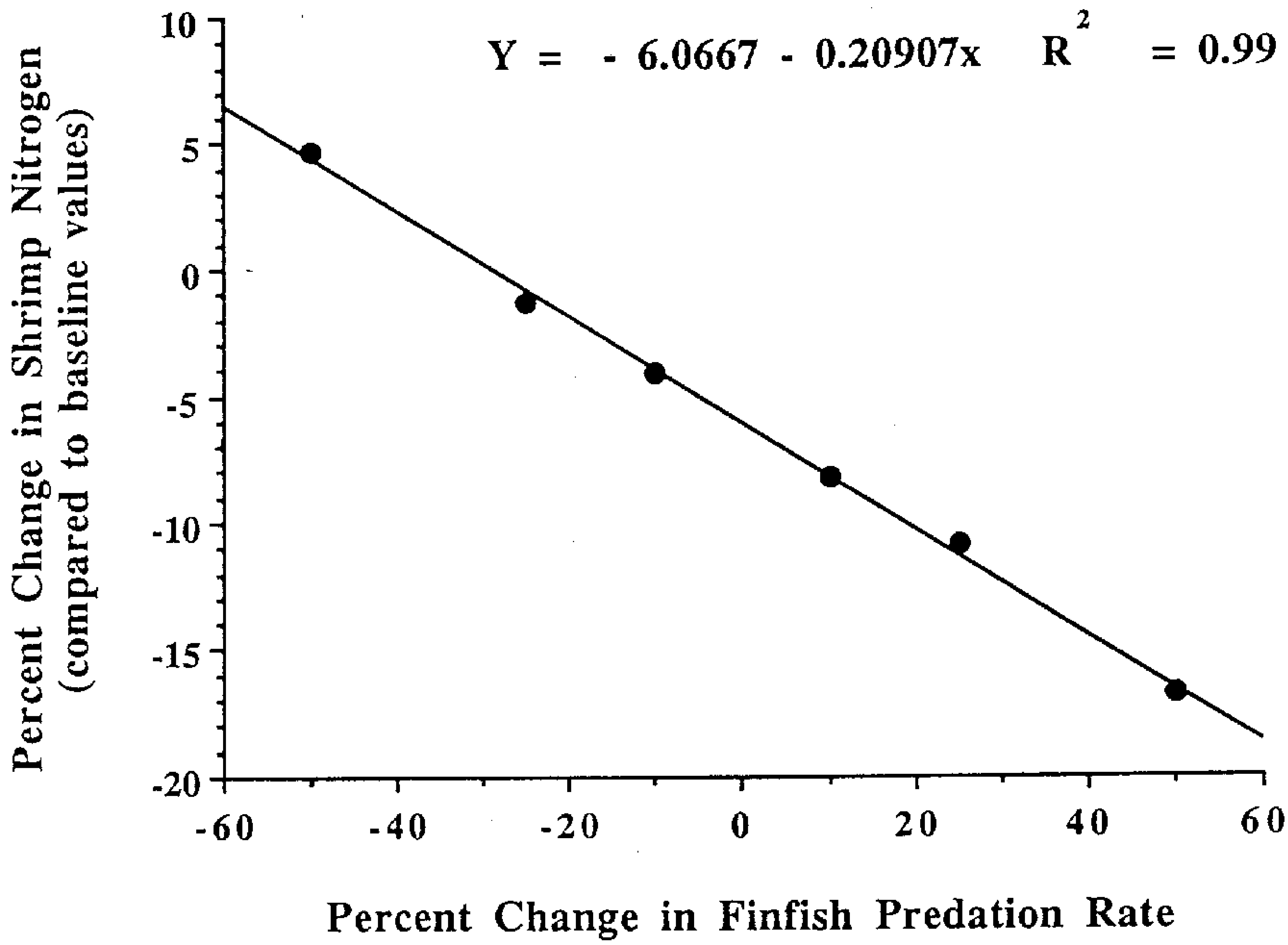

Figure 7. Effects of predation rate on shrimp nitrogen. Data reflect results from simulation Scenarios 3 and 4 which utilized sensitivity analyses in the model to examine the impacts of increasing or decreasing predation rates on the shrimp nitrogen stock.